MANUFACTURING METHOD OF CARBON NANOTUBE TRANSISTORS

BACKGROUND OF THE INVENTION

Field of Invention

The invention relates to a manufacturing method of transistors and, in particular, to a manufacturing method of carbon nanotube transistors.

Related Art

In the trend of miniaturization, the manufacturing processes of the integrated circuit (IC) based upon silicon wafers are facing bottleneck problems in optics and physics and pressures from research investments. People have started trying various kinds of nanotransistors made from nanomolecules, so that hundreds of times more transistors than the prior art can be put into a same area. A nanometer is one-billionth meter. In the development of all sorts of nanotransistors, the technique that uses carbon nanotubes as the basic building blocks is the fastest. It is expected to be the best material for nano-grade computer products in the next generation.

The carbon nanotube was discovered by Japan NEC researcher in 1991 when he was studying carbon family chemicals. It is a cylindrical carbon material with a diameter between 1 and 30 nanometers. The carbon nanotube is known to be the thinnest tube discovered in Nature. It is thermally conductive, electrically conductive, robust, chemically stable, and soft. It is mainly comprised of one or several layers of unsaturated graphene layer. These little tubes are actually elliptical micro molecules. They are formed under high temperatures in the water vapor generated by carbon arc and laser. The central portion of the carbon nanotube graphene layer completely consists of six-cite rings. Both ends of the turning points have five- or seven-cite rings. Each carbon atom has the SP2 structure. Basically, the structure and chemical properties of the graphene layer on the carbon nanotube are similar to carbon sixty (C60). The carbon nanotubes can be

semiconductors or conductors. Because of this special property, the carbon nanotube plays an important role in electronic circuits.

A necessary condition for using carbon nanotubes in future circuits is that they can be used to make transistors. The semiconductor carbon nanotube can be used as the gate in a field effect transistor (FET). Imposing a voltage can increase its conductivity to be 106 times that of the silicon semiconductor. The operating frequency can reach 1012 Hz, which is 1000 times the frequency that can reached by current CMOS. IBM has successfully used individual single wall or multi wall carbon nanotube as the channel of FET's to obtain carbon nanotube transistors for test. The single wall carbon nanotubes (SWNT's) consist of a single shell of carbon atoms. The so-called CNT is a macro carbon molecule with many properties. There are single wall CNT (SWCNT) and multiple wall CNT (MWCNT). There are three kinds of carbon nanotube preparation methods. The first is called the plasma discharging method; the second is called the laser ablation method; and the third is called the metal catalyst thermal chemical vapor deposition method, in which the carbon nanotubes are formed by using iron, cobalt, and nickel metal particles to thermally decompose acetylene or methane in a high-temperature furnace.

Using the reactions in the third type carbon nanotube production method, the disclosed manufacturing method of carbon nanotube FET's does not require the use of highly pollutant alkaline metals. The processes involved are very simple and compatible with existing IC processes.

SUMMARY OF THE INVENTION

An objective of the invention is to provide a manufacturing method of carbon nanotube transistors to solve the foregoing problems and difficulties in the prior art.

Another objective of the invention is to provide a manufacturing method of carbon nanotube transistors to simplify the conventional production processes. With currently available equipment, the production and research costs can be greatly reduced.

We disclose a general embodiment to demonstrate the invention can achieve the above objectives. The detailed steps include: forming an insulating layer on a substrate; forming a first oxide layer on the insulating layer using a solution with cobalt ion catalyst by spin-on-glass (SOG); forming a second oxide layer on the first oxide layer using a solution without the catalyst; forming a blind hole on the second oxide layer using photolithographic and etching processes, the blind hole exposing the first oxide layer, the sidewall of the second oxide layer, and the insulating layer; forming a single wall carbon nanotube (SWNT) connecting the first oxide layer separated by the blind hole and parallel to the substrate; and forming a source and a drain connecting to both ends of the SWNT, respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will become more fully understood from the detailed description given hereinbelow illustration only, and thus are not limitative of the present invention, and wherein:

FIGS. 1A through 1F show cross-sectional views of the production steps in the first embodiment of the invention;

FIGS. 2A through 2F show cross-sectional views of the production steps in the second embodiment of the invention;

FIGS. 3A through 3E show cross-sectional views of the production steps in the third embodiment of the invention; and

FIGS. 4A through 4I show cross-sectional views of the production steps in the fourth embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

FIGS. 1A through 1F show the production steps of the carbon nanotube transistors according to a first embodiment of the invention.

As shown in FIG. 1A, an insulating layer 101 is formed on a substrate 100. The insulating layer 101 can be made of SiO_2 or Si_XN_Y using the chemical vapor deposition (CVD) method.

With reference to FIG. 1B, a first oxide layer 102 containing a catalyst is formed on the insulating layer 101. First, a coating solution is prepared. The coating solution is applied on the insulating layer 101 by the SOG method. Finally, the coating solution layer (not shown) on the insulating layer is dried in two steps. The coating solution consists of at least a solution containing TEOS, pure alcohol and catalyst ions. One can also add an ammonia solution (NH_4OH + alcohol). The catalyst ion can be cobalt, nickel, or iron ion. The two-step drying includes drying at the temperature of 100~120℃ for one hour and then drying at the temperature of 350~500℃ for another hour.

As shown in FIG. 1C, a second oxide layer without the catalyst is formed on the first oxide layer 102. First, a coating solution is prepared and applied on the first oxide layer 102 by the SOG method. Afterwards, the coating solution layer (not shown) is dried. The coating solution consists at least a TEOS solution.

As shown in FIG. 1D, after exposure and developing using a mask, a blind hole 104 is formed by dry or wet etching. The blind hole 104 exposes part of the insulating layer 101, the sidewall 105 of the first oxide layer 102, and the sidewall 106 of the second oxide layer 103.

As shown in FIG. 1E, a carbon nanotube 107 is formed. Both ends of the carbon nanotube 107 are connected to the sidewall 105 of the first oxide layer 102. The alcohol (C_2H_5OH) inside the first oxide layer 102 is the reactant for the carbon nanotube 107. It reacts with the catalyst inside the first oxide layer 102 under the temperature of 850℃. The reason it does not form the carbon nanotube between the sidewall 106 of the second oxide layer is that there is no reactant and catalyst in the second oxide layer 103. Thus, the carbon nanotube 107 can be fixed between the sidewall 105 of the first oxide layer 102.

As shown in FIG. 1F, a source 108a and a drain 108b are connected to both ends of the carbon nanotube 107, respectively. The source 108a and the drain 108b can be formed using electron-beam (E-beam) photolithography along with a lift-off means.

Please refer to FIGS. 2A through 2F for the production steps in a second embodiment of the invention.

As shown in FIG. 2A, a first insulating layer 201 is formed on a substrate 200. The insulating layer 201 can be made of SiO_2 or Si_XN_Y using the chemical vapor deposition (CVD) method.

With reference to FIG. 2B, a source 208a and a drain 208b are formed on the first insulating layer 201. The detailed steps include using metal sputtering to form a metal layer (not shown) on the first insulating layer 201 and using photolithography and etching to form the source 208a and the drain 208b. They are separated by a gap 204. The metal can be titanium.

As shown in FIG. 2C, a first oxide layer 202 with a catalyst and a second oxide layer 203 with no catalyst are formed on the substrate 200 that has the source 208a, the drain 208b, and the first insulating layer 201. To form the first oxide layer, one first prepares a coating solution and applies the coating solution on the source 208a and the drain 208b by the SOG method, filling the gap 204. Afterwards, the coating solution layer (not shown) covering the source 208a, the drain 208b, and the gap 204 is dried. The coating solution for the first oxide layer 202 consists of at least a solution containing TEOS, pure alcohol and catalyst ions. One can also add an ammonia solution (NH_4OH + alcohol). The catalyst ion can be cobalt, nickel, or iron ion. To form the second oxide layer 203, one first prepares a coating solution and applies the coating solution on the first oxide layer 202 by the SOG method. Afterwards, the coating solution (not shown) on the first oxide layer is dried. The coating solution here consists of at least a TEOS solution.

As shown in FIG. 2D, after exposure and developing using a mask, a blind hole 209 is

formed by dry or wet etching. The blind hole 209 exposes part of the insulating layer 201, the sidewall 205 of the first oxide layer 202, the sidewall 206 of the second oxide layer 203, and the sidewall 210 of the source 208a and the drain 208b.

As shown in FIG. 2E, a carbon nanotube 207 is formed. Both ends of the carbon nanotube 207 are connected to the sidewall 205 of the first oxide layer 202. The alcohol (C_2H_5OH) inside the first oxide layer 202 is the reactant for the carbon nanotube 207. It reacts with the catalyst inside the first oxide layer 202 under the temperature of 850℃. The reason it does not form the carbon nanotube between the sidewall 206 of the second oxide layer is that there is no reactant and catalyst in the second oxide layer 203. Thus, the carbon nanotube 207 can be fixed between the sidewall 205 of the first oxide layer 202.

As shown in FIG. 2F, a second insulating layer 211 is formed on the second oxide layer 203 that contains the blind hole 209. The forming method can be the CVD method. Once the second insulating layer 211 fills the blind hole 209, it pushes down the carbon nanotube 207 in the blind hole 209. The carbon nanotube 207 thus has a concave shape and touches the sidewall 210 of the source 208a, the drain 208b and part of the first insulating layer 201. Therefore, the carbon nanotube 207 connects the source 208a and the drain 208b. The second insulating layer consists of SiO_2 or Si_xO_y.

Please refer to FIGS. 3A through 3F for the production steps in a third embodiment of the invention.

As shown in FIG. 3A, a first insulating layer 301 is formed on a substrate 300. The insulating layer 301 can be made of SiO_2 or Si_XN_Y using the chemical vapor deposition (CVD) method.

With reference to FIG. 3B, a source 308a and a drain 308b are formed on the first insulating layer 301. The detailed steps include using metal sputtering to form a metal layer (not shown) on the first insulating layer 301 and using photolithography and etching to form the source 308a and the drain 308b. They are separated by a gap 304. The metal

can be titanium.

As shown in FIG. 3C, a first oxide layer 302 with a catalyst and a second oxide layer 303 with no catalyst are formed on the substrate 300 that has the source 308a, the drain 308b, and the first insulating layer 301. To form the first oxide layer, one first prepares a coating solution and applies the coating solution on the source 308a and the drain 308b by the SOG method, filling the gap 304. Afterwards, the coating solution layer (not shown) covering the source 308a, the drain 308b, and the gap 304 is dried. The coating solution for the first oxide layer 302 consists of at least a solution containing TEOS, pure alcohol and catalyst ions. One can also add an ammonia solution (NH_4OH + alcohol). The catalyst ion can be cobalt, nickel, or iron ion. To form the second oxide layer 303, one first prepares a coating solution and applies the coating solution on the first oxide layer 302 by the SOG method. Afterwards, the coating solution (not shown) on the first oxide layer is dried. The coating solution here consists of at least a TEOS solution.

As shown in FIG. 3D, after exposure and developing using a mask, a blind hole 309 is formed by dry or wet etching. The blind hole 309 exposes part of the insulating layer 301, the sidewall 305 of the first oxide layer 302, the sidewall 306 of the second oxide layer 303, and some surface and the sidewall 312 of the source 308a and the drain 308b. The sidewall 312 of the source 308a and the drain 308b protrudes from the sidewall 305 of the first oxide layer 302 and the sidewall 306 of the second oxide layer 303.

As shown in FIG. 3E, a carbon nanotube 307 is formed. Both ends of the carbon nanotube 307 are connected to the sidewall 305 of the first oxide layer 302. The alcohol (C_2H_5OH) inside the first oxide layer 302 is the reactant for the carbon nanotube 307. It reacts with the catalyst inside the first oxide layer 302 under the temperature of 850℃. The reason it does not form the carbon nanotube between the sidewall 306 of the second oxide layer is that there is no reactant and catalyst in the second oxide layer 303. Thus, the carbon nanotube 307 can be fixed between the sidewall 305 of the first oxide layer 302. Both end of the carbon nanotube 307 are connected to the surfaces of the source 308a and

the drain 308b.

Please refer to FIGS. 4A through 4I for the production steps in a fourth embodiment of the invention.

As shown in FIG. 4A, a first insulating layer 401 is formed on a substrate 400. The insulating layer 401 can be made of SiO_2 or Si_XN_Y using the chemical vapor deposition (CVD) method.

As shown in FIG. 4B, a first oxide layer 402 with a catalyst is formed on the first insulating layer 401. First, one prepares a coating solution and applies it on the first insulating layer 401 by the SOG method. Afterwards, the coating solution layer (not shown) on the first insulting layer 401 is dried in two steps. The coating solution consists at least a solution containing TEOS, pure alcohol and catalyst ions. One can further add an ammonia solution (NH_4OH + alcohol). The catalyst ion can be one of the cobalt, nickel, and iron ions. The two-step drying includes drying under the temperature of 100~120℃ for one hour and then under the temperature of 350~500℃ for another hour.

As shown in FIG. 4C, a second oxide layer 403 with no catalyst is formed on the first oxide layer 402. To form the second oxide layer 403, one first prepares a coating solution and applies it on the first oxide layer 402 by the SOG method. Afterwards, the coating solution layer (not shown) on the first oxide layer 402 is dried. The coating solution here consists at a TEOS solution.

As shown in FIG. 4D, after exposure and developing using a mask, a blind hole 404 is formed by dry or wet etching. The blind hole 404 exposes part of the insulating layer 401, the sidewall 405 of the first oxide layer 402, and the sidewall 406 of the second oxide layer 403.

As shown in FIG. 4E, a carbon nanotube 407 is formed. Both ends of the carbon nanotube 407 are connected to the sidewall 405 of the first oxide layer 402. The alcohol (C_2H_5OH) inside the first oxide layer 302 is the reactant for the carbon nanotube 307. It

reacts with the catalyst inside the first oxide layer 302 under the temperature of 850℃. The reason it does not form the carbon nanotube between the sidewall 306 of the second oxide layer is that there is no reactant and catalyst in the second oxide layer 403. Thus, the carbon nanotube 407 can be fixed between the sidewall 405 of the first oxide layer 402.

As shown in FIG. 4F, a second insulating layer 411 is formed on the second oxide layer 403 that contains the blind hole 404. The second insulating layer 411 deposited in the blind hole 404 covers the carbon nanotube 407 and pushes it down for the carbon nanotube 407 to touch the first insulating layer 401.

As shown in FIG. 4G, a photoresist pattern 413 is formed by photolithography to fill the blind hole 404 and to cover part of the second insulating layer 411 at the blind hole 411. The photoresist pattern 413 does not cover the second insulating layer 411 outside the blind hole.

As shown in FIG. 4H, the area uncovered by the photoresist pattern 413 is removed by wet etching. The removed part includes the first oxide layer 402 and the second oxide layer 403 that are not covered by the photoresist pattern 413. After the photoresist pattern 413 is removed, one is left with the carbon nanotube 407 on the first insulating layer and the protruding part 412 covering the carbon nanotube 407 and above the second insulating layer 411. The protruding part 412 of the second insulating layer exposes both ends 407a, 407b of the carbon nanotube 407.

As shown in FIG. 4I, a source 408a and a drain 408b are connected to the two ends 407a, 407b of the carbon nanotube 407. The forming steps include first depositing a metal layer (not shown) on the first insulating layer 401 that contains the second insulating layer 414, and then using photolithography and etching processes to form the source 408a and the drain 408b from the metal layer.

Certain variations would be apparent to those skilled in the art, which variations are considered within the spirit and scope of the claimed invention.